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Fabrication and mechanical characterization of boron carbide reinforced aluminium matrix composites

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ABSTRACT

Aluminium Matrix Composites (AMCs) have gained importance in various industries because of their good mechanical properties such as wear resistance, low density, high strength and good structural rigidity. Aluminium Metal Matrix composites are preferred in the field of aerospace, military, automotive, marine and in many other domestic applications. The aluminium matrix can be strengthened by reinforcing with hard ceramic particles like SiC, Al_2O_3, B_4C etc. In the present work, aluminium 6061 alloy was chosen as the matrix material and boron carbide particulate of 25 micron size is chosen as the reinforcement with varying weight percentages (5% and 10%). The composite is prepared by using Stir Casting Technique. The hardness and the impact (Charpy) behaviour of prepared composites were examined. Hardness of Al6061 was increased and impact strength was decreased by

addition of B_4C particles. Scanning Electron Microscopy (SEM) micrographs reveal the uniform distribution of B_4C particles in aluminium alloy.

Keywords: Al6061, Boron Carbide, Stir-Casting, Impact strength, Hardness.

1. INTRODUCTION

Metal Matrix Composites (MMCs) are the combination of two or more distinct phases that have improved properties than the monolithic alloy. Aluminium MMCs are greatly developing in the recent years and have potential to replace the high cost bronze and cast alloys in several applications [1]. Due to their unique combination of properties such as high specific strength, high corrosive resistance, high elastic modulus, good thermal stability, high hardness, high wear resistance, superior strength to weight ratio and light weight [2]. Aluminium matrix being lighter can be strengthened by reinforcing less dense hard ceramic particles such as SiC, Al_2O_3, TiB, B_4C etc which shows improvement in properties [13,12]. With the increase in demand for less denser and high stiffer component, Al matrix composite found its place in the area of aerospace and non-aerospace categories. The replacement of the nickel cast iron in conventional diesel engine piston crown by aluminium matrix composites has resulted in a lighter, more abrasive and cheaper product. Because of low thermal expansion and conductivity Al based composites are used as heat sinks in chips carrier multilayer boards, high speed integrated circuit packages for computers and in base plates for electronic equipments [11]. Number of technique are being employed for production of MMCs like solid state methods, liquid state methods, deposition and insitu process [15,9], out of which liquid state methods in particular stir casting has an attractive economic aspect combined with wide selection of materials and processing conditions [21,10]. In traditional stir casting process, reinforcement material is added to molten matrix and poured in to permanent moulds after stirring [5]. Stir casting process enhances better bonding between matrix and reinforcement because of the stirring action. The main concerns in fabricating MMCs is difficulty is achieving homogeneous distribution of particles [6,7,8].

Most of the research work dedicated to fabrication of Al based MMCs is concentrated around SiC, Al_2O3, TiB_2 as reinforcement material; but use of boron carbide particulate is very limited due to high cost and poor wetting with the Al matrix below 1100^{0}C [16]. B4C is having hardness of 3800 Hv considered as third hardest material next to diamond and Cubic boron nitride, with good impact and wear resistance, low specific density (2.52 g/cc), low thermal conductivity (35 W/mK) and high stiffness (445 GPa) which makes it suitable to find place in applications like ballistic armour, as abrasive, nozzles etc. Wettability of ceramic particles can be improved by several ways which includes pre-treatment, use of surface active agents [17] which decreases surface tension and interfacial forces [19]. Coating of B_4C particles with Ti powder results in formation of complex surface layer of TiB and TiC [18] and these interfacial products have grater metallic character to their bonding, increasing better incorporation of B_4C particles into melt. Use of K_2TiF_6 halide salt during casting is another method being practiced which has resulted in improved bonding between Al and B_4C particles facilitating better mechanical properties in the composite material [9]. Further, during melt stirring, getting proper distribution of reinforcing particles in the matrix is challenging. After wetting the particles sink or float due to density differences as a consequence, the dispersion becomes non homogeneous which may lead to clustering and segregation of particles at a particular place in the melt. Such effect could lead to several micro structural defects like porosities, oxides inclusions and interfacial reactions [19]. B_4C is a robust material having excellent chemical and thermal stability, high hardness and low density. Hence, B_4C reinforced aluminium Matrix Composite has gained more attraction with low cost casting route [20,21,10]. It is used for manufacturing bullet proof vests, armour tanks etc. [22]. In this paper fabrication and Mechanical characterization, viz Impact strength, Rockwell hardness and metallographic structure of AMCs reinforced with B_4C are detailed.

2. EXPERIMENTAL PROCEDURE

2.1. Fabrication process

The fabrication of AA6061-B_4C composite used in this study was carried out by using Stir Casting method. The chemical composition of the Al 6061 alloy matrix was presented in Table 1. Particulates of the B_4C having mean size of 25 μm are used as reinforcement. Firstly AA6061 alloy in the form of 25 mm diameter rods cut into 75mm length was placed in a clay graphite crucible. It was then melted in a resistance heated muffle furnace to the desired temperature of 850^{0}C. In the mean time B_4C particulates were preheated in another crucible to a temperature of 250^{0}C to remove moisture, and the die was preheated to a temperature of 600^{0}C. Then the boron carbide particulates were mixed into the molten metal. The crucible was covered with a flux and degassing agents to improve the quality of aluminium composite casting. The mixture was stirred continuously by using mechanical stirrer for 10 minutes at an impeller speed of 400 rpm. The melt temperature was maintained at 800^{0}C during addition of the particles. The molten metal was

then poured into the preheated die to cast plates of 100mmx100mmx10mm size. The process parameters used for stir casting are shown in Table 2. The stir casting set up used for producing composite plates and the composite castings were shown in Figures 1 and 2 respectively.

Table 1 Chemical composition of Aluminium alloy (AA6061)

Elements	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
% by weight	0.64	0.293	0.261	0.095	0.88	0.033	0.089	0.032	Balance

Table 2 Process parameters used for Stir Casting

Parameters	Units	Value
Temperature of Melt	^{0}C	850
Preheating temperature of B_4C Particles	^{0}C	250
Preheating temperature of die	^{0}C	600
Spindle Speed	rpm	400
Stirring time	min	10
Powder feed rate	g/s	0.8-1.2

Figure 1 Stir Casting Set-up used for fabrication of Composites (AA 6061/B_4C)

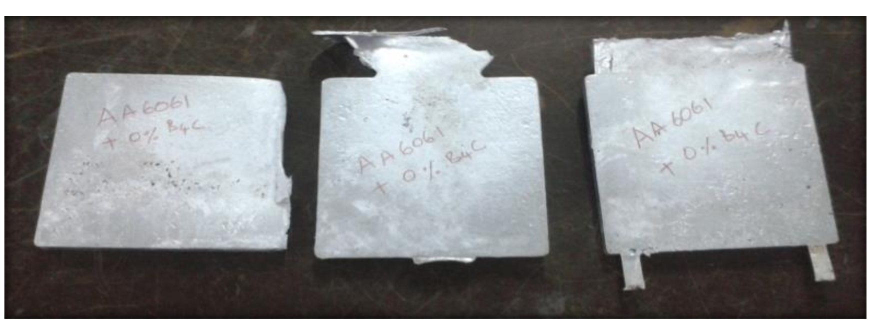


Figure 2 Casted Aluminium Composite Plates (AA6061+B_4C 0, 5, 10%)

2.2. Micristructural characterization &mechanical testing

The specimens from the cast AMCs were prepared for microstructural studies as per the standard metallographic procedure. After thorough polishing using abrasive paper and velvet cloth, the specimens were etched using Keller's reagent (HNO_3 + HCL + HF). The etched specimens were observed under optical microscope. Scanning Electron Microscopy (SEM) was done to know the distribution of B_4C particles in aluminum alloy. The Hardness test was carried out at room temperature using Rockwell hardness tester. Hardness measured at different location of the specimen on scale-B, at a load of 100kgf, using 1/16" Tungsten Ball Indenter. Impact test was carried out at room temperature using Impact tester to evaluate the toughness. The specimen is supported at two ends like a simply supported beam measured and reading was taken by breaking the specimen due to the impact of the pendulum.

3. RESULTS AND DISCUSSIONS

3.1. Evaluation of microstructure

The optical micrographs of the fabricated AMCs with different wt. % of B_4C reinforcement of 25μm size are shown in figure 3 (a), (b) and (c). The micrographs revealed that B_4C particles are uniformly distributed in the aluminium matrix for 5 and 10 wt. % B_4C particles, respectively. This behaviour can be attributed to the effective stirring action and the use of appropriate process parameters, in addition to the greater wettability of the B_4C particles with the aluminium alloy. The greater wettability of B_4C particles with the aluminium alloy might be due to formation of liquid B_2O_3 layer on the B_4C particles. This liquid layer, which forms above certain temperature on the surface of B_4C, increases wettability as there is a liquid-liquid reaction, whereas the same pattern resulted [23]. It is also observed that the addition of B_4C particles prevented the grains from growing as large as the pure AA6061 alloy. Addition of reinforcement particles in the melt increased the number of nucleation sites, by providing additional substrate during solidification, and decreased the grain size.

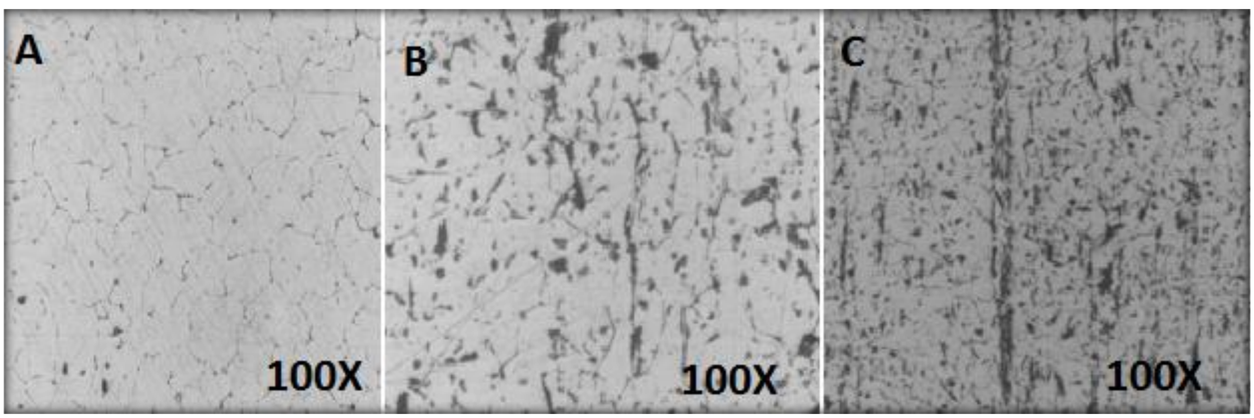
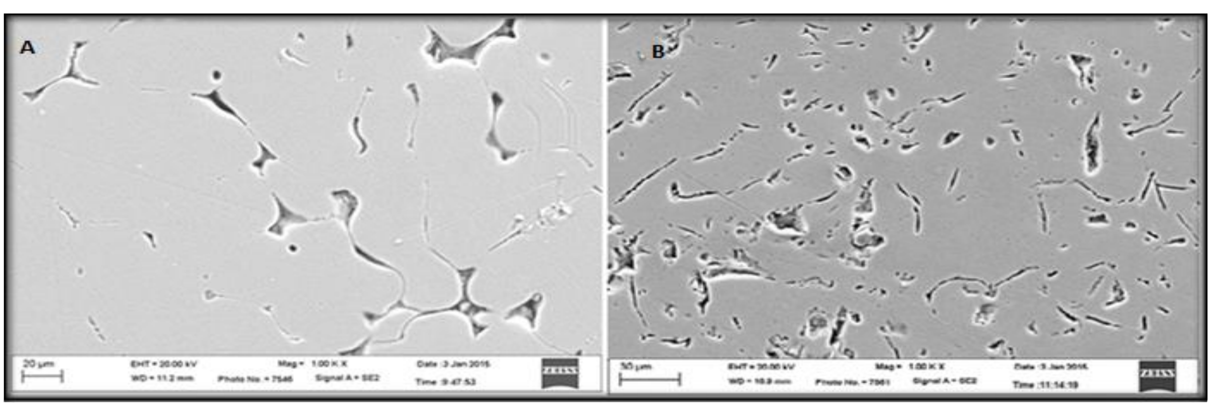


Figure 3 Microstructure of Composite Specimen (a) AA6061 (b) AA6061 + 5% B_4C (c) AA6061 +10% B_4C



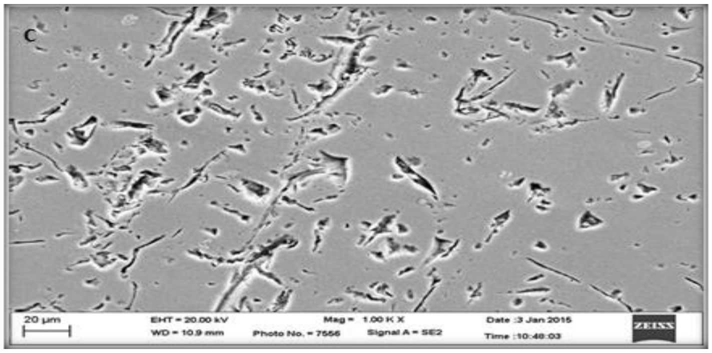


Figure 4 SEM micrographs of Aluminium Matrix Composites (a) AA6061 (b) AA6061+5% B_4C (c) AA6061+10% B_4C

All conclusions derived at based on; optical microscopic examinations are strongly affirmed by Scanning Electron Microscopy. The SEM micrographs of the AMCs with different wt. % of B4C reinforcement are shown in figures 4 (a), (b) and (c).

3.2. Mechanical Properties

The mechanical properties such as hardness and impact strength of the AA6061/B_4C composites are discussed briefly in the following sections.

3.2.1. Hardness of the composites

The hardness results of the AA6061/B_4C composites are shown in
Figure 5. The Hardness was measured at room temperature using Rockwell hardness tester with at least six indentations of each sample and then the average values were used to calculate hardness number. The load used on Rockwell's hardness tester 100kg at dwell time of 20 seconds for each sample. The hardness value is increased by increasing the wt % of B_4C reinforcement particles in the composites, as the presence of hard reinforcement particles on the surface resists the plastic deformation of the material. The strength of the grain boundaries increases to maximum level and dislocation of atoms is decreased by increasing the wt% of reinforcement, which gives strength to the matrix and thereby hardness of the composite gets increased. The same phenomenon is observed [9].

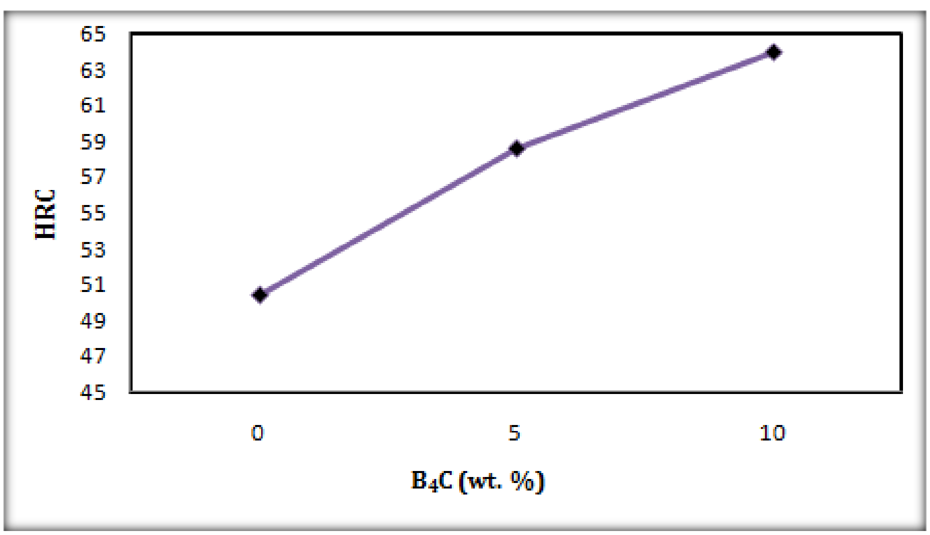


Figure 5 The effects of percentage of B_4C particles on the hardness of AMCs

3.2.2. Impact strength of the composites

The impact strength of the AA6061/B_4C composites are shown in figure 6. It is observed that the toughness is decreased by increasing the weight percentage of the B_4C particles in the composite. This is due to the addition of B_4C in various percentages with

aluminum, the brittleness of the material also increased. Because of high brittleness, the impact strength of the material is decreased.

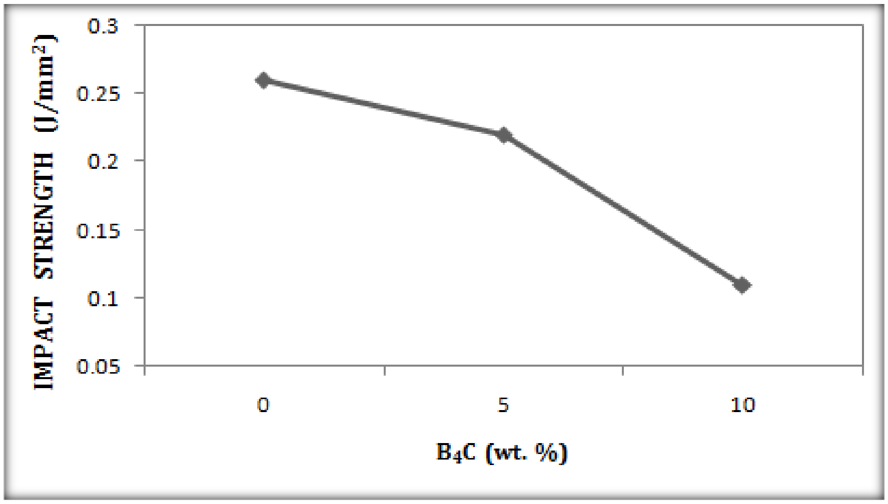


Figure 6 The effects of percentage of B4C particulates on the toughness of AMCs

4. CONCLUSIONS

The AA6061/B_4C composites were produced by stir cast route with different weight percentage of reinforcement and the microstructure, mechanical properties were evaluated. From this study, the following conclusions are derived.

1.Production of homogeneous AA6061/B_4C composite could be achieved by using Stir Casting setup detailed in this paper.

2.The Scanning Electron Microscopic (SEM) study revealed the presence of B_4C particles in the composite and the grain boundary thickening is uniform and well distributed over the matrix.

3.The Rockwell hardness of the composites increased from 50.4 HRB to 64 HRB with incremental weight percentage of B_4C particles.

4.The B_4C reinforcement has reduced the impact strength of Aluminum Matrix Composites (AMCs) from 0.22 J/mm^2 to 0.11 J/mm^2.

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